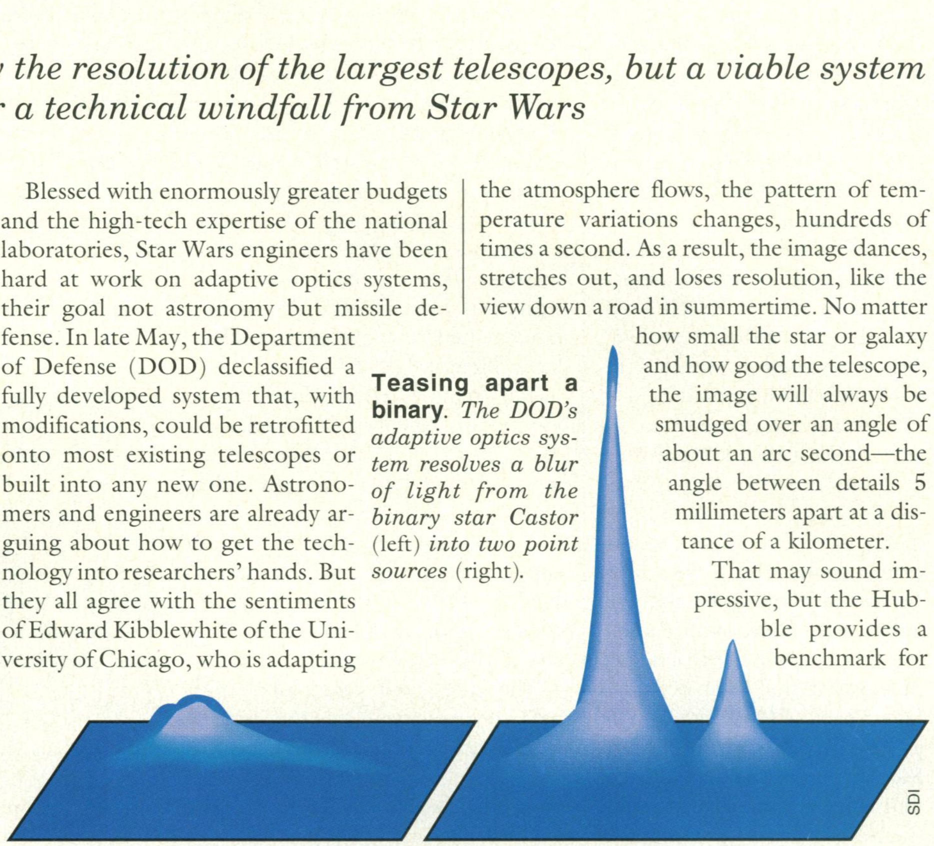
Untwinkling the Stars

Adaptive optics could multiply the resolution of the largest telescopes, but a viable system will cost money to build. Enter a technical windfall from Star Wars

SEEN WITH THE HUBBLE SPACE TELESCOPE, an erupting star called Eta Carinae is violence itself, a brilliant core with puffballs on either side and a jet of material shooting out of the top, surrounded by visible shock waves. You'd never know this from the ground; state-of-the-art telescopes reveal only a peanut-shaped blob with a cap. The difference is in the air: Light from Eta Carinae has to negotiate Earth's turbulent atmosphere, and by the time the light reaches our best ground-based telescopes, the star looks far less interesting than it really is.

For decades astronomers have looked longingly at a technology called adaptive optics to bring heavenly viewing down to Earth by canceling atmospheric distortion. Testifying to the promise of the technology was the report of the National Research Council's Astronomy and Astrophysics Survey Committee, published early this year, in which adaptive optics headed the list of recommended moderate-sized equipment programs. But the complexity and expense of this blend of optics, computers, and intricate mechanical engineering have made for slow progress. Now a windfall from the Strategic Defense Initiative has brought astronomers' dreams into focus. The technology transfer will give astronomers "an enormous boost," says Wayne van Citters, program director for Astronomical Instrumentation and Development at the National Science Foundation (NSF), "that would have taken years and a lot of money to rediscover."

Blessed with enormously greater budgets and the high-tech expertise of the national laboratories, Star Wars engineers have been hard at work on adaptive optics systems, their goal not astronomy but missile defense. In late May, the Department of Defense (DOD) declassified a fully developed system that, with modifications, could be retrofitted onto most existing telescopes or built into any new one. Astronomers and engineers are already arguing about how to get the technology into researchers' hands. But they all agree with the sentiments of Edward Kibblewhite of the University of Chicago, who is adapting the new system for astronomers' use at the Massachusetts Institute of Technology's Lincoln Laboratory: "If [the system] works as well as we think it will, everyone will want one on their telescopes."



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Teasing apart a binary. *The DOD's adaptive optics system resolves a blur of light from the binary star Castor* (left) *into two point sources* (right).

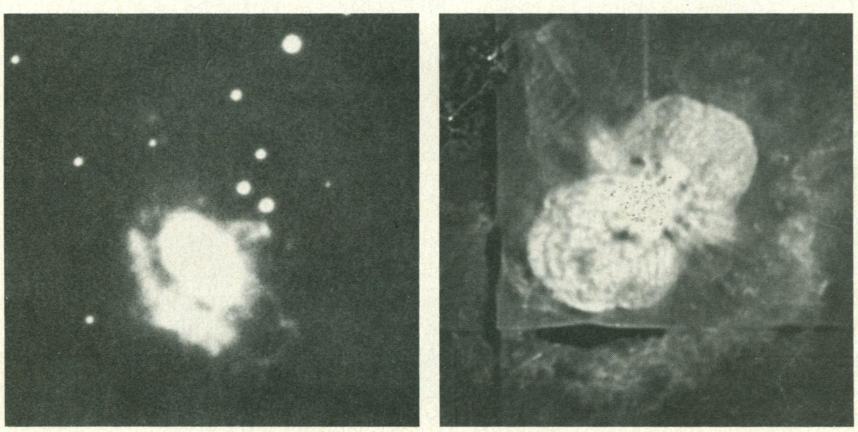
Adaptive optics is nothing less than a means of restoring starlight to its original condition. Light travels from a star or galaxy in a plane wave—a flat, straight wavefront—until it reaches the atmosphere, where patches of varying temperature distort the wavefront. As the atmosphere flows, the pattern of temperature variations changes, hundreds of times a second. As a result, the image dances, stretches out, and loses resolution, like the view down a road in summertime. No matter how small the star or galaxy and how good the telescope, the image will always be smudged over an angle of about an arc second—the angle between details 5 millimeters apart at a distance of a kilometer.

That may sound impressive, but the Hubble provides a benchmark for what ground-based telescopes could achieve if they could escape this smudging. When the crippled space telescope is fixed, its resolution will be limited only by the so-called diffraction limit, a fundamental physical limit set by the diffraction of light off the mirror. For a mirror the size of Hubble's, the diffraction limit is 0.05 arc seconds, 20 times sharper than the atmosphere allows.

To achieve such blinding clarity on Earth, a typical adaptive optics system intercepts some of the light collected by the telescope's primary mirror and sends it to a sensor that detects the distortions in the wavefront. A computer analyzes the pattern of distortions picked up by the sensor and sends signals to an array of tiny pistons called actuators, which controls the shape of a small, flexible or segmented mirror. That adaptive mirror, by distorting the light into a precisely equal and opposite pattern, corrects the image before sending it to the astronomer's eye, or—more likely these days—to a photographic or electronic detector. The whole process happens hundreds of times a second, so that the final image the astronomer receives is not only sharp but motionless as well.

One of the toughest technical hurdles has been that the wave sensors need a lot of

A sharper star. *Eta Carinae as seen by the 4-meter telescope at the Cerro Tololo Inter-American Observatory* (left) *and by the Hubble Space Telescope* (right).



Nolan Walborn and Aura

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light, and most objects astronomers are interested in—distant galaxies, for example—are dim. Seven years ago, the French astronomers Renaud Foy and Antoine Labeyrie proposed a simple solution: create an artificial star by shooting a laser into the atmosphere, where it is reflected by dust or creates a spot of fluorescence in the thin layer of sodium ions 90 kilometers up. Place the artificial star next to the dim object, do the adaptive corrections on the artificial star, and apply the same corrections to the dim object you really want to see.

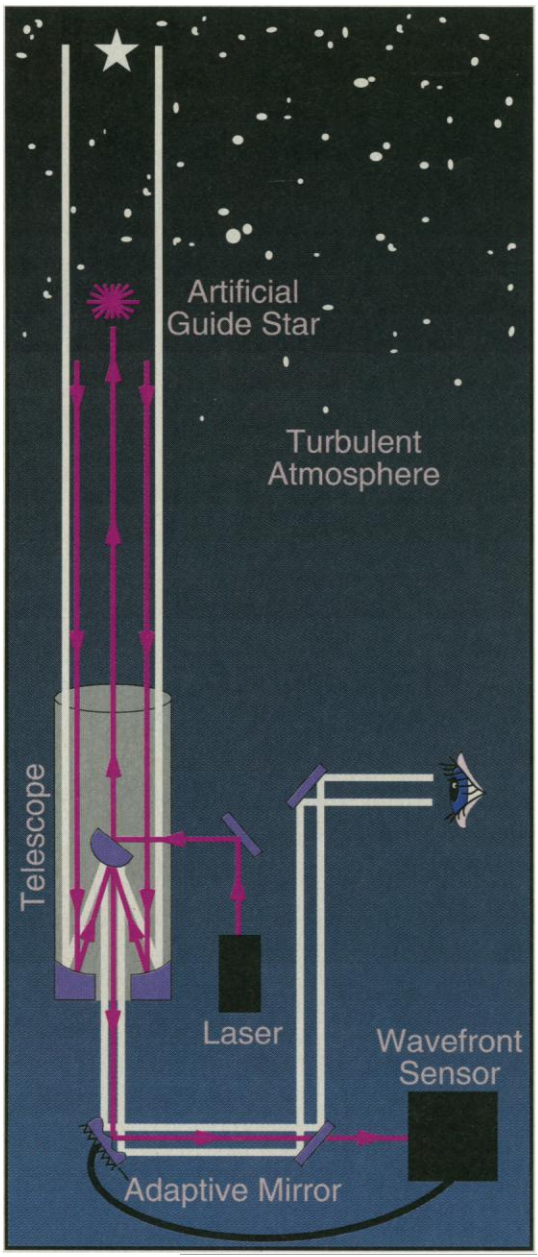
But astronomers' limited resources have ruled out that kind of starmaking, leaving them to toy with prototype systems that can be used only on relatively bright targets. What's more, those experimental systems work only at infrared wavelengths, which are less distorted by the atmosphere than visible light. That doesn't mean the prototypes are less than ingenious. Sam Durrance at Johns Hopkins University is building a system whose adaptive mirror is made of celluloid film, bent not by a cluster of actuators but by a pattern of changing voltages. François Roddier at the University of Hawaii is working on a system with a novel sensor that can analyze the pattern of distortions in very faint objects—faint enough to eliminate the need for a guide star (see *Science*, 31 August 1990, p. 987). And Roger Angel of the University of Arizona at Tucson has tested a system that has no wavefront sensor at all but instead has a neural network computer program trained to relate the blurriness of the image to the corrections that must be made to the adaptive mirror.

But Star Wars engineers have even the most ingenious systems of astronomers beat. For the past 10 years, the Strategic Defense Initiative Office (SDIO) has been developing technologies for correcting atmospheric distortion in laser beams fired into space from the ground. As part of that work, in April Star Wars engineers completed testing of a full-fledged adaptive optics system, complete with a laser that created an artificial guide star at an altitude of 6 kilometers. Although the test, on Haleakala in Hawaii, used a 60-centimeter telescope—puny by astronomical standards—the system made visible-light images with a resolution of .2 arc seconds, right at the telescope's diffraction limit.

Not long afterward, because of changes in emphasis within the Star Wars program, the SDIO shut down its adaptive optics project and released details of this system to the NSF for use by astronomers. And the SDIO has afforded astronomers direct access to the system at Lincoln Laboratory, where it is being installed on a 1.2-meter telescope.

Before this Star Wars technology is fitted to every telescope from Cerro Tololo to Mount Graham to Mauna Kea, it will have to be modified. Because of the modest size of the telescope in the test, the system was limited to bright stars. For it to work on dimmer objects, says Charles Primmerman, a Lincoln Laboratory engineer who helped develop the classified system, it will have to be mated with 3- or 4-meter mirrors, requiring more actuators—a thousand or so instead of the 241 of the existing system—to put a finer pattern of bumps and hollows into the adaptive mirror.

How adaptive optics works. *Light from a laser-created artificial guide star is analyzed by a wavefront sensor, which detects atmospheric distortions and tells an adaptive mirror how to compensate for them.*



Correcting for the atmosphere's effect on dimmer objects also requires an artificial star placed at the very top of the atmosphere, above all its turbulence. Aram Mooradian, a colleague of Primmerman's, says he has already created such stars by training a laser on the 90-kilometer-high sodium layer. And Primmerman thinks a system incorporating these added elements is just a matter of time.

Which brings the astronomical community back to the big hurdle: money. Lincoln Laboratory is prepared to develop and test an astronomically useful system, says Primmerman—but for a fee of $15 million. That's out of the question, says the NSF's van Citters: "We don't have that kind of money." Van Citters says that the NSF considers the spending recommendation of the National Research Council's recent report—$35 million over the next 10 years—to be more in the ballpark. Primmerman retorts: "NSF and astronomers collectively have not faced up to what these things cost."

The difference between the views of astronomers and the Star Wars engineers is not only financial but also cultural. Accepting Primmerman's proposal, said Roger Angel, "would be completely alien." Astronomers' instruments are usually not store-bought but homemade. "When you've made it at home," says Kibblewhite, who is the NSF's principal investigator for the newly transferred system, "you can also fix it when it goes wrong." Angel agrees: "If you can think it through yourself, you don't pay someone else to do it." Tell us what's been done, says Angel, and "we'll take it from there, thank you."

But astronomers will do their best to make sure the technology transfer is not delayed for long. They are well aware that adaptive optics is no panacea: Though it can wipe away atmospheric distortion, it can do nothing about atmospheric absorption of gamma-rays, x-rays, and most ultra-violet and infrared light. The best view at those wavelengths will always be found in space. And because adaptive optics can only correct a small patch of sky at a time, only space telescopes will be able to give high-resolution observations of extended objects like nearby galaxies or distant clusters of galaxies. But what adaptive optics can do will be more than enough. As Kibblewhite puts it, "If it works, it revolutionizes astronomy." ■ ANN FINKBEINER

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